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OPTICAL HAZARD EVALUATION OF DENTAL CURING LIGHTS
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AGENCY ABERDEEN PROVING GROUND MD P ERIKSEN ET AL.

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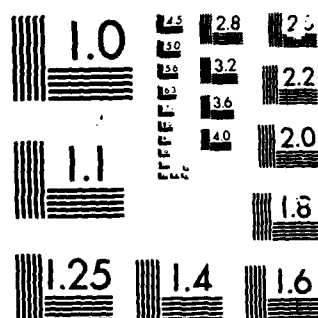
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**UNITED STATES ARMY
ENVIRONMENTAL HYGIENE
AGENCY**

ABERDEEN PROVING GROUND, MD 21010-5422

NONIONIZING RADIATION PROTECTION STUDY, NO. 25-42-0334-86
/OPTICAL HAZARD EVALUATION OF DENTAL CURING LIGHTS
AUGUST - NOVEMBER 1985

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DEPARTMENT OF THE ARMY
U. S. ARMY ENVIRONMENTAL HYGIENE AGENCY
ABERDEEN PROVING GROUND, MARYLAND 21010-5422

REPLY TO
ATTENTION OF

MSHB-RL

14 March 1986

SUBJECT: Nonionizing Radiation Protection Study No. 25-42-0334-86, Optical Hazard Evaluation
of Dental Curing Lights, August - November 1985

Commander
US Army Health Services Command
ATTN: HSCL-P
Fort Sam Houston, TX 78234-6000

EXECUTIVE SUMMARY

The purpose and recommendations of the enclosed report follow:

a. Purpose. To evaluate potential ocular hazards associated with the use of dental curing lights and to make recommendations to eliminate exposure of personnel to hazardous levels of optical radiation.

b. Recommendations.

(1) To ensure regulatory compliance, the following recommendation is made. Do not permit unprotected personnel to stare directly into the dental curing lights at distances shorter than 25 cm.

(2) To ensure good radiation protection practice, the following recommendation is made. Provide eye protectors which filter wavelengths below 500 nm to reduce discomfort if desired by individual users or if surface lamination is applied.

FOR THE COMMANDER:

Enc1

RALPH R. CARESTIA
Colonel, MS
Director, Radiation and
Environmental Sciences

CF:
HQDA(DASG-PSP) (w/enc1)
Cdr, HSC (HSDS) (w/enc1)
Cdr, AMC (AMCSG-S) (w/enc1)
Cdr, MICOM (AMSHI-XO) (w/enc1)
Comdt, AHS (MSHA-IPM) (w/enc1)
Cdr, DDEAMC (PVNTMED Svc) (w/enc1)
Cdr, WRAMC (PVNTMED Svc) (w/enc1)
Cdr, MEDDAC, Ft Bragg (PVNTMED Svc) (2 cy) (w/enc1)
Cdr, MEDDAC, Ft Eustis (PVNTMED Svc) (2 cy) (w/enc1)
Cdr, MEDDAC, Redstone (PVNTMED Svc) (2 cy) (w/enc1)
Cdr, DENTAC, Ft Bragg (2 cy) (w/enc1)
Cdr, DENTAC, Ft Eustis (2 cy) (w/enc1)
Cdr, DENTAC, Redstone (2 cy) (w/enc1)

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DEPARTMENT OF THE ARMY
U. S. ARMY ENVIRONMENTAL HYGIENE AGENCY
ABERDEEN PROVING GROUND, MARYLAND 21010-5422

REPLY TO
ATTENTION OF

HSHB-RL

NONIONIZING RADIATION PROTECTION STUDY NO. 25-42-0334-86
OPTICAL HAZARD EVALUATION OF DENTAL CURING LIGHTS
AUGUST - NOVEMBER 1985

1. AUTHORITY.

a. 1st End, HQ HSC, HSCL-P, 16 October 1985, to letter, MEDDAC, Fort Eustis, HSXH-PVNTMED, 25 September 1985, subject: Request for Evaluation.

b. 1st End, HQ AMC, AMCSG-S, 26 November 1984, to letter, US Army Missile Command, AMSMI-XO, 19 November 1984, subject: Request for Technical Evaluation of 3M Optilux Dental Visible Light Curing Units.

c. Letter, MEDDAC, Fort Bragg, HSXC-PM, undated, subject: Non-Ionizing Radiation Study.

2. REFERENCES. A list of references is provided in Appendix A.

3. PURPOSE. To evaluate potential ocular hazards associated with the use of dental curing lights and to make recommendations to eliminate exposure of personnel to hazardous levels of optical radiation.

4. GENERAL.

a. Background. Dental curing (photopolymerization) lights are used to cure resins used for dental restorations (tooth "fillings") and are now found in most Army dental clinics. Previously, resins were cured with near-ultraviolet (UV-A) radiation. Now, most resins are cured with blue light. Most dental curing light units in this study consisted of an enclosed light source (and power supply), which was coupled to a handheld "gun" by a fiber optic cable or light-guide. From the fiber-optic cable or the protruding tip of the "gun," light was directed to the resin to be cured.

b. Evaluated Units. A total of 13 units were evaluated by USAEHA personnel: six at the DENTAC, Fort Bragg, North Carolina; one at the Edgewood Area Dental Clinic, Aberdeen Proving Ground (APG), Maryland; one at Rhodes Dental Clinic, Fort Sam Houston, Texas (as part of USAEHA Survey No. 25-42-0208-86, reference 6); one at the DENTAC, Redstone Arsenal, Alabama; and four at USAEHA, APG. A list of the evaluated units, their identification, and their manufacturer can be found in Appendix B.

Use of company names does not imply endorsement by the US Army, but is intended only to assist in identification of a specific product.

c. Radiometric Terms and Units. A table of commonly used radiometric and photometric terms and units is provided in Appendix C.

d. Instrumentation. A spectroradiometer [employing an Oriel double monochromator (2.5-nm bandwidth), a Hamamatsu R212 photomultiplier, an Oriel High Voltage power supply, and a Keithley Model 614 Electrometer] was used for the measurements of spectral irradiance. The spectroradiometer was calibrated against a 1000-W FEL-type standard lamp, with calibration traceable to the National Bureau of Standards.

5. FINDINGS.

a. Evaluation. The measured spectral irradiance for 12 of the different types of dental lights is plotted in Appendix D. From these spectral measurements, the following quantities used for the hazard evaluation (in accordance with references 3 and 4) were derived: total irradiance (E), effective UV irradiance (E_{eff}), UV-A irradiance (E_{UVA}), blue-light irradiance (E_b) and illuminance (E_v). Furthermore, the blue-light radiance (L_b), the thermal-hazard radiance (L_R) and the luminance (L_v) were calculated using the source diameter (D) and the measurement distance ($r = 30$ cm). The results are shown in Appendix E.

b. Exposure Conditions. During a curing procedure, the dentist is normally not exposed to the light source directly. The light source is a tungsten-halogen lamp whose output is transmitted via a quartz rod or a fiber-optic cable to the tooth under treatment. The dentist can be exposed to reflected light from the tooth or to light that has been transmitted through the transilluminated tooth. Occasionally, if the dentist is curing a preparation on the front teeth from behind, he can view the exposed area of the tip. The calculations in this report assume worst-case conditions: direct exposure to the tip of the curing device and a viewing distance such that the source subtends an angle greater than 11 milliradians. It must be emphasized that the dentist is only occasionally exposed to the tip directly and, during the normal course of a photopolymerization, is only exposed to the reflected or transmitted source (see the following Figure).

c. Special Features. One of the Caulk Prisma-Lite units emitted an audible tone every 10 seconds while the light was on. The Command units were equipped with a timer, adjustable for an on-time between 1 and 30 seconds.

d. Warning Labels. Warning labels were not attached to any of the units.

6. DISCUSSION.

a. Spectral Output. The output of a specific type of curing light can vary within a factor of two, depending on the age of the light source. Some units emit a relatively high portion of their output in the UV-A spectral region. Earlier types of curing lights, like the NUVA-Light, were UV-A lights with very little visible output, whereas the currently used



FIGURE. Use of a Dental Curing Light at the Edgewood Area Dental Clinic, APG. Left photograph shows tip of applicator and right photograph shows applicator in use. The dentist's eyes were more than 50 cm from the tip.

resins are best cured with blue light. The advantage with blue-light-cured (polymerized) resins is a greater and more consistent depth of cure, whereas UV-A radiation provides a more shallow (albeit harder) depth of cure. Generally, a complete curing of a resin takes 30-50 seconds.

b. Potential Hazards. Three potential hazards could exist which require evaluation: UV hazard to the cornea and lens, blue-light retinal hazard, and thermal burn retinal hazard. The measurements revealed that the UV hazard is nonexistent; i.e., no actinic UV radiation was detected and the UV-A emission from all units is sufficiently below the occupational exposure limits to cause harmful effects under normal operating conditions. In effect, the only hazards requiring careful study were the blue-light and thermal hazards. Both of these hazards have their most pronounced adverse effect at short visible wavelengths (blue). The blue-light hazard is dominant for lengthy exposure times (>10 sec) and the thermal hazard is dominant for short exposure times (<10 sec). Only for one of the evaluated units (Command No. 1) was there a theoretical thermal hazard, and then only if one deliberately stares directly into the light at a very close distance (less than 15 cm) and for more than 5 seconds. However, because the luminance (brightness) was also very high, the eye's aversion response would limit the exposure time to about 0.25 sec and, since a viewing distance of 15 cm is less than the near accommodation point of 25 cm for the normal individual, this is not a realistic viewing situation. It is more likely that an operator would be exposed to the blue-light hazard during normal treatment procedures. Thus, only the blue-light hazard is of practical concern. Therefore, only the maximum stare time, T_{max} [calculated from the blue-light radiance (L_b) and the TLV \odot for this quantity (references 3 and 4)], is shown in Appendix E. It is seen that T_{max} ranges from 4 minutes to more than 100 minutes. Assuming total additivity of blue-light retinal exposures over an 8-hour workday, a total of eight 30-second cures with the light-source (positioned so that the dentist could see the exposed tip) would exceed the occupational exposure limit (TLV). Since the tip is normally directed away from the eye, this is an unrealistic operating condition. Again, since the luminance is high, and since normal treatment times are short, these lights can be considered nonhazardous for both operator and patient when used as intended. Since this study was performed, a scientific article has appeared (reference 7) which suggests eyewear be used; however, this was based upon an assumption of a heavier workload, i.e., 17 to 81 applications a day where the tip would be seen.

c. Reflections. For reasons described in the above paragraph, reflections, either specular or diffuse, can be considered nonhazardous under normal use conditions. Only under excessively heavy use could reflections be of possible concern.

\odot TLV - Threshold Limit Value established by the American Conference of Government Industrial Hygienists, Cincinnati, Ohio. Use of trademarked names does not imply endorsement by the US Army but is intended only to assist in identification of a specific product.

d. Eyewear, Luminance and Comfort. It is not necessary to use protective eyewear during normal use when operating dental lights. However, since the dental lights' luminance exceeds the maximal comfort luminance of 10^4 cd/m² for indoor work, the operator may, for comfort, choose to wear either slightly colored plastic eyewear (sunglass type) or to attach special, small-diameter, clip-on plastic lenses to the protruding tip of the "gun." Under heavy use (e.g., total laminations of front teeth), eye protectors may be advisable when using some units. Both tip shields and spectacles are readily available from various dental supply houses (see reference 8). The cost per spectacle varies greatly, but need not be excessive. For example, Younger Optics, has spectacles at a cost of approximately \$15.00 each.

7. CONCLUSION. Dental curing lights can be considered nonhazardous under normal operating conditions for restorative dentistry. The operator may wish to reduce specularly or diffusely reflected luminances by using colored/tinted eyewear or by attaching colored/tinted clip-on plastic shields to the tip of the handheld gun.

8. RECOMMENDATION.

a. Do not permit unprotected personnel to stare directly into dental curing lights at distances shorter than 25 cm (AR 40-46, C1, paragraph 1-40).

b. Provide eye protectors which filter wavelengths below 500 nm to reduce discomfort if desired by individual users or if surface lamination is applied. (This recommendation is based on good radiation protection practice.)

9. ACKNOWLEDGMENTS. Mr. Paul Eriksen, visiting scientist, Danish National Institute of Occupational Health, Copenhagen, was the principal author for this report and has since returned to Denmark. CPT Willem P. Van de Merwe, Nuclear Science Officer, Laser Microwave Division, was a co-author for this report and has since departed this Agency.

James K. Franks

JAMES K. FRANKS
Acting Chief, Laser Branch
Laser Microwave Division

Patrick M. Moscato

PATRICK M. MOSCATO
Physical Science Technician
Laser Microwave Division

APPROVED:

Arthur B. Webb

ARTHUR B. WEBB
LTC, MS
Chief, Laser Microwave Division

APPENDIX A

REFERENCES

1. AR 40-5, 1 June 1985, Preventive Medicine.
2. AR 40-46, 6 February 1974, Control of Health Hazards from Lasers and Other High Intensity Optical Sources, CI, 15 November 1978.
3. USAEHA Technical Guide 085, Hazard Analysis of Broad-Band Optical Sources, September 1981.
4. D. H. Sliney and M. L. Wolbarsht, Safety with Lasers and Other Optical Sources, Plenum Press, New York, 1980.
5. Aeromedical Review 1-84, Visible-light Resin Curing Lights, Brooks Air Force Base, Texas, US Air Force School of Aerospace Medicine, March 1984.
6. Letter, USAEHA, HSHB-RL, 15 November 1985, subject: Nonionizing Radiation Protection Survey No. 25-42-0208-86, Lasers and High-Intensity Optical Sources, Brooke Army Medical Center, Fort Sam Houston, Texas, 31 July - 2 August 1985.
7. O. L. Ellingson, R. J. Landry, and R. G. Bostrom, "An evaluation of optical radiation emissions from dental visible photopolymerization devices," J Amer Dent Assn, 112(1): 67-70(1986)
8. E. A. Berry III, D. G. Pitts, P. R. Francisco, and W. H. Von der Lehr, "An evaluation of lenses designed to block light emitted by light curing units," J Amer Dent Assn, 112(1): 70-75 (1986)

APPENDIX B

IDENTIFICATION OF EVALUATED UNITS

Caulk Prisma-Lite (1)

Model No.: Pr-1, 115V-50/60Hz-3.5A.

Mfg: L.D. Caulk Co., Div. of Dentsply, Int. Inc., Midford, DE 19963.

Caulk Prisma-Lite (2)

Model No.: Pr-1, SN 25425, 115V-50/60Hz-3.5A.

Mfg: L.D. Caulk Co., Div. of Dentsply, Int. Inc., Midford, DE 19963.

Caulk Prisma-Lite (3)

Model No.: Pr-1, SN C1636, 115V-50/60Hz-3.5A.

Mfg: L.D. Caulk Co., Div. of Dentsply, Int. Inc., Midford, DE 19963.

Command (1)

Model No.: NUVA-Lite, SN 15691, 120V-60Hz-1.7A.

Mfg: Kerr Div. of Sybron Corp., 28200 Wick Rd., Romulus, MI 48174.

Command (2)

Model No.: NUVA-Lite, SN 18228, 120V-60Hz-1.7A.

Mfg: Kerr Div. of Sybron Corp., 28200 Wick Rd., Romulus, MI 48174.

Command (3)

Model No.: NUVA-Lite, SN 15537, 120V-60Hz-1.7A.

Mfg: Kerr Div. of Sybron Corp., 28200 Wick Rd., Romulus, MI 48174.

SPECTRA Lite (made in GDR)

Model No.: Spectra light Polymerization Unit, SN 7030-3-362.

Agent: Peatron Corp., P.O. Box 771, Walingford, CT 06492.

Norland Opticure

Model No.: Light Gun UVC 5000, SN A001448

Mfg: Norland Products, Inc., 695 Joyce Kilmer Ave., New Brunswick, NJ 08902.

Western Electric

Model No.: 345 Simplex UV Curing light, SN 0092.

Mfg: Archie Solomon Mfg. Corp., 950 Sun Valley Drive, P.O. Box 395,
Roswell (Atlanta), GA 30077.

Caulk NUVA-Lite

Model No.: L102, SN 23877, 115V-60Hz-2A.

Mfg: L.D. Caulk Co., Div. of Dentsply, Int. Inc., Midford, DE 19963.

Midwest Insite

Model No.: 162, SN 13339

Mfg: American Midwest, 901 West Oakton, Des Plaines, IL 60018.

Elipar Curing Light

SN: V60438

Mfg: Seefield/Overbau, West Germany.

Optilux Curing Light

Mfg: Demetron Research Corp., 5 Ye Old Road, Dandury, CT 06810.

APPENDIX C

USEFUL CIE RADIOMETRIC AND PHOTOMETRIC TERMS AND UNITS^{1,2}

RADIOMETRIC				PHOTOMETRIC			
Term	Symbol	Defining Equation	SI Unit and Abbreviation	Term	Symbol	Defining Equation	SI Units and Abbreviation
Radiant Energy	Q_e	$Q_e = \int \Phi_e dt$	Joule (J)	Luminous Energy (Quantity of Light)	Q_v	$Q_v = \int \Phi_v dt$	lumen-second (lm-s) or (talbot)
Radiant Energy Density	W_e	$W_e = \frac{dQ_e}{dV}$	Joule per cubic meter (J-m ⁻³)	Luminous Energy Density	W_v	$W_v = \frac{dQ_v}{dV}$	talbot per cubic meter (lm-s-m ⁻³)
Radiant Flux (Radiant Power)	Φ_e, P	$\Phi_e = \frac{dQ_e}{dt}$	Watt (W)	Luminous Flux (Luminous Power)	Φ_v	$\Phi_v = 683 \int \frac{dQ_v}{d\lambda} V(\lambda) d\lambda$	lumen (lm)
Radiant Exitance	R_e	$R_e = \frac{dQ_e}{dA} = \int L_e \cos \theta d\Omega$	Watt per square meter (W-m ⁻²)	Luminous Exitance	R_v	$R_v = \frac{dQ_v}{dA} = \int L_v \cos \theta d\Omega$	lumen per square meter lm-m ⁻²
Irradiance or Radiant Flux Density (Dose Rate in Photobiology)	E_e	$E_e = \frac{dQ_e}{dA}$	Watt per square meter (W-m ⁻²)	Illuminance (Luminous Flux density)	E_v	$E_v = \frac{dQ_v}{dA}$	lumen per square meter (lm-m ⁻²) or lux (lx)
Radiant Intensity	I_e	$I_e = \frac{dQ_e}{d\Omega}$	Watt per steradian (W-sr ⁻¹)	Luminous Intensity (candlepower)	I_v	$I_v = \frac{dQ_v}{d\Omega}$	lumen per steradian (lm-sr ⁻¹) or candela (cd)
Radiance ³	L_e	$L_e = \frac{d^2 Q_e}{d\Omega dA \cos \theta}$	Watt per steradian and per square meter (W-sr ⁻¹ -m ⁻²)	Luminance ³	L_v	$L_v = \frac{d^2 Q_v}{d\Omega dA \cos \theta}$	lumen per steradian and per square meter (lm-sr ⁻¹ -m ⁻²) or candela per square meter (cd-m ⁻²)
Radiant Exposure (Dose in Photobiology)	H_e	$H_e = \frac{dQ_e}{dA} = \int E_e dt$	Joule per square meter (J-m ⁻²)	Light Exposure	H_v	$H_v = \frac{dQ_v}{dA} = \int E_v dt$	lux-second (lx-s)
				Luminous Efficacy (of radiation)	K	$K = \frac{\Phi_v}{\Phi_e}$	lumen per watt (lm-w ⁻¹)
				Luminous Efficiency (of broad band radiation)	$V(\lambda)$	$V(\lambda) = \frac{K_\lambda}{K_m} = \frac{K_\lambda}{683}$	unitless
Radiant Efficiency ⁵ (of a source)	η_e	$\eta_e = \frac{P}{P_1}$	unitless	Luminous Efficacy ⁵ (of a source)	η_v	$\eta_v = \frac{\Phi_v}{P_1}$	lumen per watt (lm-w ⁻¹)
Optical Density ⁶	D_e	$D_e = -\log_{10} I_e$	unitless	Optical Density ⁶	D_v	$D_v = -\log_{10} I_v$	unitless
				Retinal Illuminance in Trolands	E_t	$E_t = L_v \cdot S_p$	troland (td) = luminance in cd-m ⁻² times pupil area in mm ²

- The units may be altered to refer to narrow spectral bands in which the term is preceded by the word *spectral*, and the unit is then per wavelength interval and the symbol has a subscript λ . For example, spectral irradiance E_{λ} has units of W-m⁻²-m⁻¹ or more often, W-cm⁻²-nm⁻¹.
- While the meter is the preferred unit of length, the centimeter is still the most commonly used unit of length for many of the above terms and the nm or μ m are most commonly used to express wavelength.

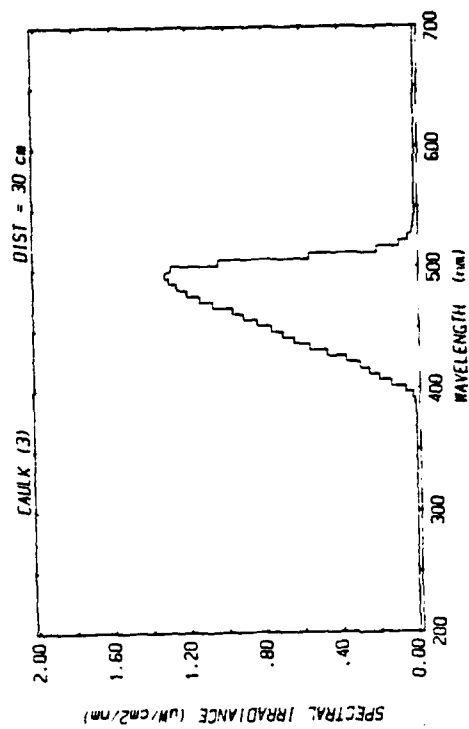
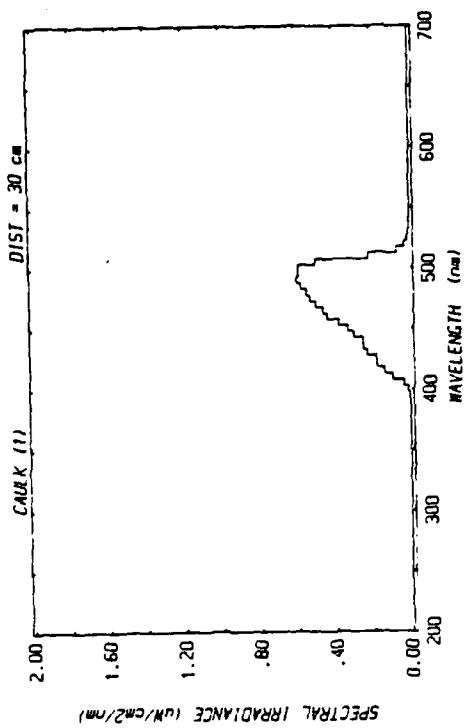
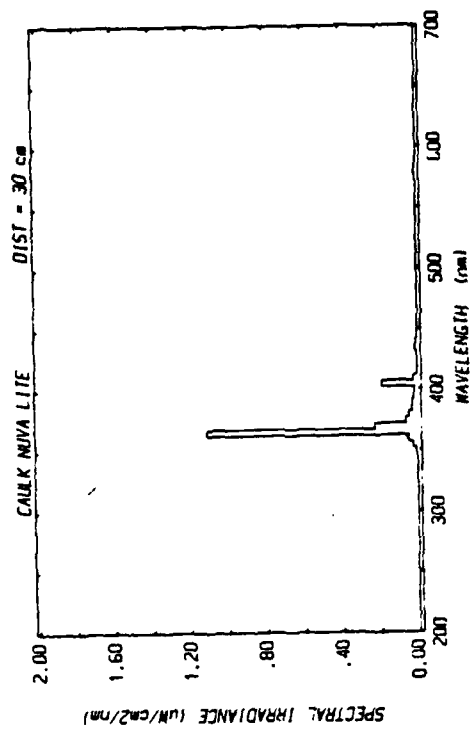
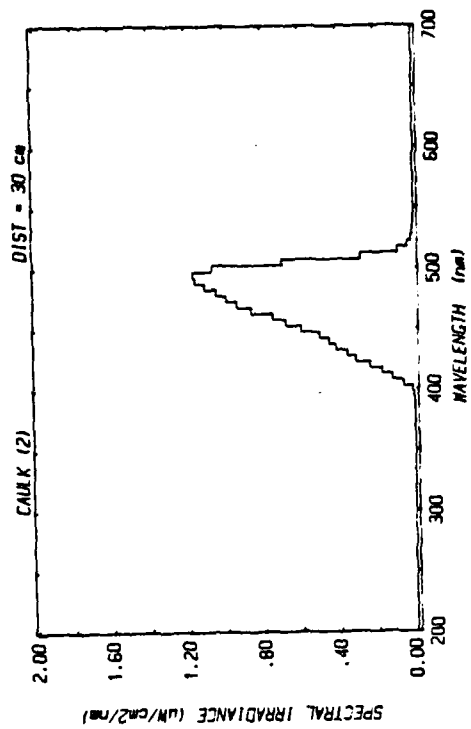
- At the source $L = \frac{dI}{dA \cos \theta}$ and at a receptor $L = \frac{dE}{dA \cos \theta}$

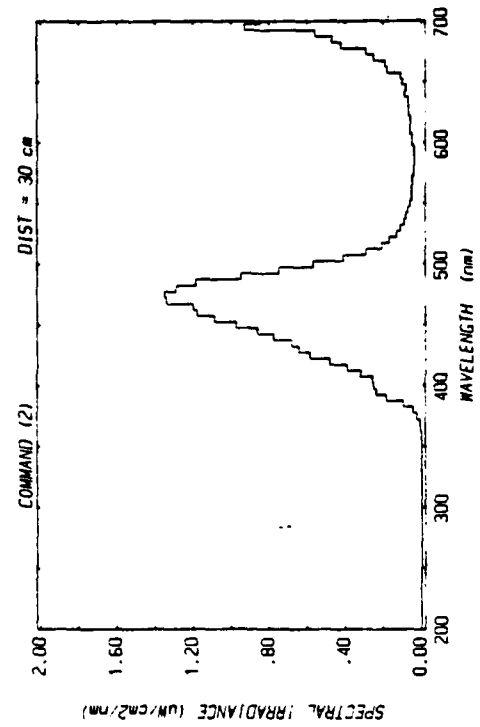
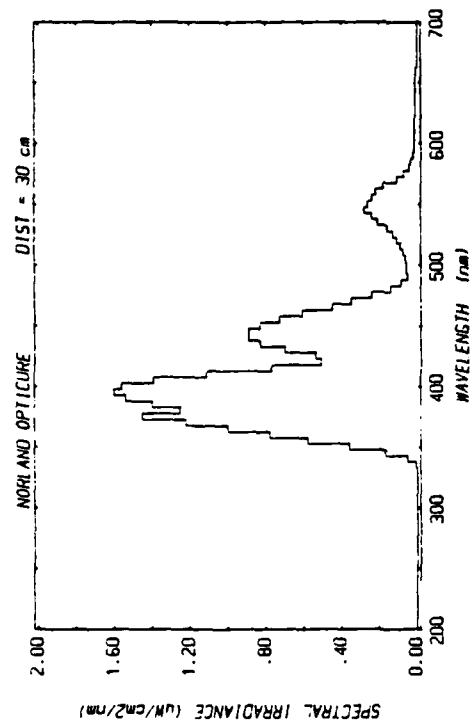
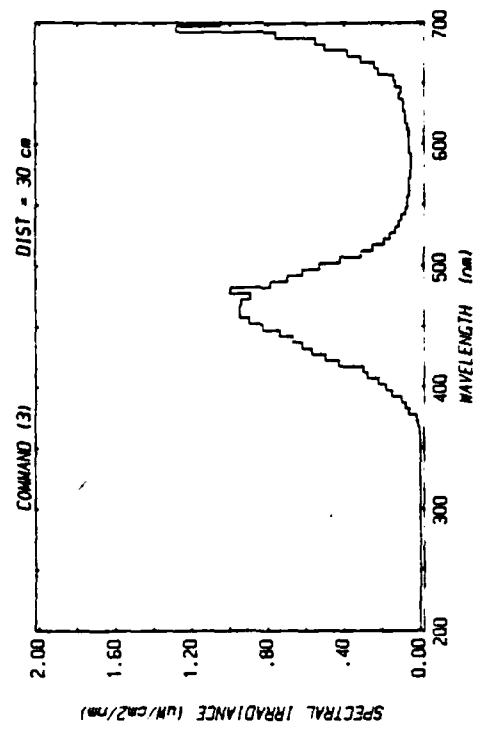
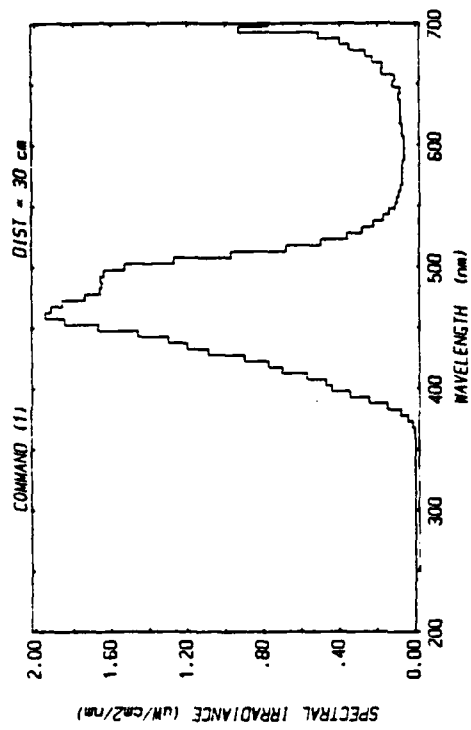
- $K_m = K$ at 555 nm.
- P_1 is electrical input power in watts.

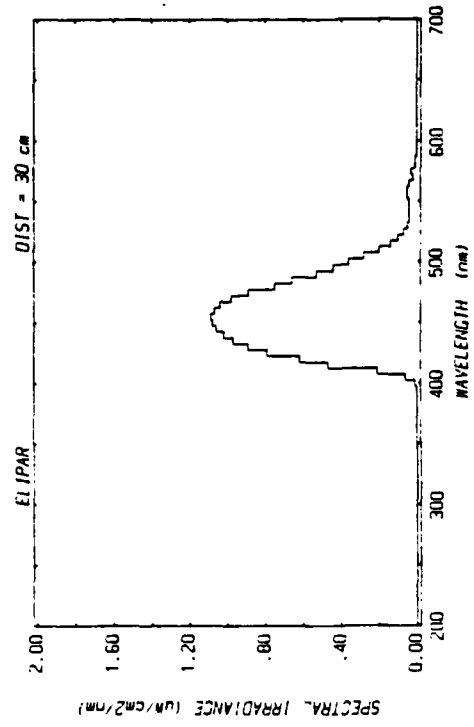
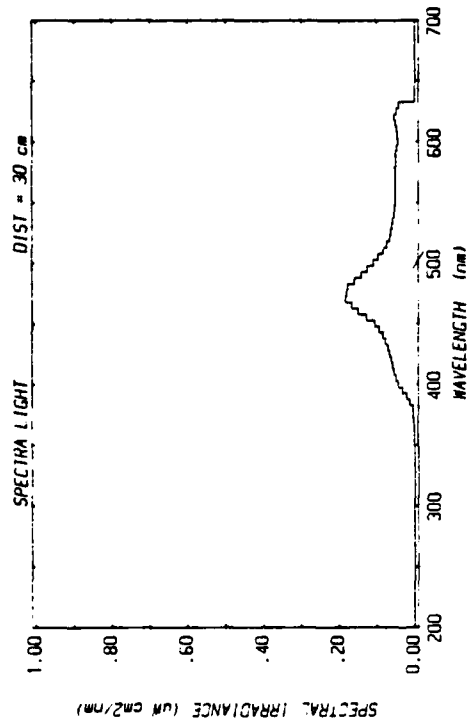
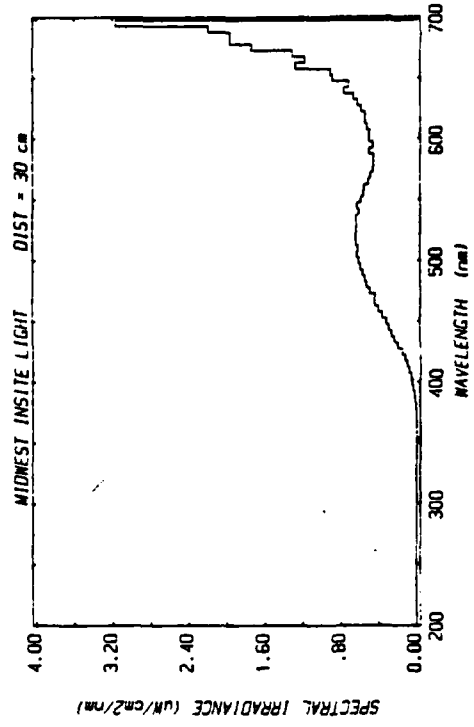
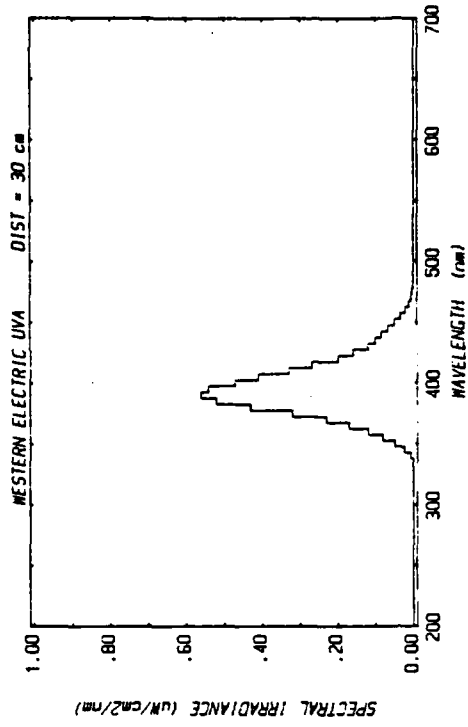
- v is the transmission.
- S_p = Area of Pupil in mm².

APPENDIX D

SPECTRAL IRRADIANCE OF 12 of 13 OF THE DENTAL CURING LIGHTS







APPENDIX E
MEASURED AND CALCULATED RADIMETRIC AND PHOTOMETRIC QUANTITIES USED TO DESCRIBE THE OUTPUT OF DENTAL CURING LIGHTS*

Source	D mm	E uWcm ⁻² (0.3 m)	E _{eff} uWcm ⁻² (0.3 m)	E _{uVA} uWcm ⁻² (0.3 m)	E _a uWcm ⁻² (0.3 m)	E _v lx (0.3 m)	L _v cdm ⁻²	I _a Wcm ⁻² Sr ⁻¹	I _v Wcm ⁻² Sr ⁻¹	T _{max} (L _a) min
Cauk Prisma-Lite (1)†	5	40	ND	0.07	12	41	1.9x10 ⁵	0.61	0.060	28
Cauk Prisma-Lite (2)‡	5	88	ND	0.24	46	95	4.4x10 ⁵	2.1	0.21	8
Cauk Prisma-Lite (3)‡	5	71	ND	0.05	37	73	3.3x10 ⁵	1.7	0.17	10
Command (1)‡	5	190	ND	5.5	95	220	1.0x10 ⁶	4.5	0.43	4
Command (2)‡	5	120	ND	3.6	58	110	5.1x10 ⁵	2.8	0.27	6
Command (3)‡	5	110	ND	2.2	46	110	5.0x10 ⁵	2.3	0.22	8
SPECTRA-Lite‡	5	34	ND	0.90	12	37	1.7x10 ⁵	0.31	0.030	56
Norland Opticure‡	7	130	ND	61	43	92	2.1x10 ⁵	1.1	0.10	17
Western Electric**	7	26	ND	16	6.4	0.57	1.3x10 ³	0.16	0.015	110
Cauk NUVA-Lite‡	10	9.4	ND	8.1	0.4	0.55	6.3x10 ²	0.043	0.0043	--
Midwest Insite**	5	202	ND	0.45	21	414	1.9x10 ⁵	1.7	0.096	17
Elipar**	7	81	ND	0.00	56	63	1.5x10 ⁵	1.3	0.13	13
Denetron Optilux††	9	--	ND	--	--	73	3.2x10 ⁵	--	--	--

* The permissible exposure time is given in minutes

† Evaluated at USAEHA; bulb close to burnout

‡ Evaluated at Fort Bragg, North Carolina

§ Evaluated at Fort Sam Houston, Texas

¶ Evaluated at USAEHA; new unit

** Evaluated at USAEHA; old unit

†† Evaluated at Redstone Arsenal, Alabama

ND - not detectable

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